CFD Analysis of Shell and Tube Heat Exchanger with Flower Baffle Attached in the Tube Side of the Heat Exchanger with SiO_2 Nanofluid Water as a Base Fluid

Aman Kumar[1], Ajay Singh[2], Nitin Barodia [3]

[1]*MTech Student, Dept. of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*

[2]*Professor, Dept. of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*

[3]Professor, *Dept. of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*

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Abstract - *A CFD analysis of a shell and tube heat exchanger with a creative floral baffle design is shown in the abstract. The purpose of the study is to assess how the floral baffle affects convective heat transfer coefficient and heat transfer rate. Conventional baffles are frequently used in traditional heat exchangers, which may reduce their total thermal efficiency. The goal of the flower baffle is to improve the heat exchanger's thermal performance by drawing inspiration from the complex and effective forms seen in nature. The fluid flow and heat transfer properties are analysed and contrasted with a typical heat exchanger setup with traditional baffles using CFD simulations and numerical modelling. The heat exchanger fitted with the floral baffle performs at a much higher rate of heat transfer than the traditional design, according to the CFD study. Additionally, there is a discernible improvement in the convective heat transfer coefficient, suggesting a more effective heat exchange mechanism with lower thermal resistances. To sum up, the new floral baffle design shows a lot of promise for raising the shell and tube heat exchangers' heat transfer efficiency. This discovery has significant implications for sectors including power generation, chemical processing, and refrigeration that depend on heat exchangers. To verify the numerical results and determine if the suggested floral baffle design is practically applicable, more investigation and experimental validation are needed. If successful, the flower baffle could revolutionize heat exchanger technology, contributing to enhanced energy efficiency and sustainability across various industrial sectors.*

***Key Words*: Shell and Tube Heat Exchanger, Nanofluid, Flower Baffle, Rate of Heat Transfer, ANSYS, CFD Analysis**

1. INTRODUCTION

A heat exchanger is a mechanical apparatus that recycles the thermal energy contained within the working fluid. The shell and tube are a versatile heat exchanger due to its versatility in design and is extensively used in various sectors for cooling of turbine and compressor, oil industries, for refrigeration and air conditioning, and many more. The shell and tube heat exchanger consists of a collection of tubes contained within a shell. The baffle plates are one of the essential barriers situated within the shell to create turbulence which will boost the rate of heat transfer and also offer support to the lengths of the tube. Various types of baffle plates are employed in the shell and tube heat exchanger, including longitudinal flow baffles, impingement baffles (used to safeguard the bundle in cases of high entrance velocity), and orifice baffles. Heat exchangers are an integral part of the sectors such as: power plants, process industries, oil refining and so on. Shell and tube heat exchangers (STHE) currently account for 40% of the equipment used in various industries. Hence, it is vital to prioritise attention on this equipment in order to enhance the functionality of this gadget. Baffles and tube configuration and their arrangement have a tremendous effect on the performance of this kind of heat exchanger. One can refer to common segmental baffle problems as: creation of fouling in dead zone, producing high pressure drop because of dead zones, remarkable flow streams between shell and baffle, tube and baffle because of construction tolerance and decreasing the lifetime of the heat exchanger due to the vibration caused by the fluid flow across the tube bundle [1,2]. Gao et al. [3] studied the discontinuous baffle with different angles experimentally. Their result show that 40° helix angle is the best among the other investigated helix angles [3]. In an industrial research project in Tabriz, Zeyninejad Movassag et al. [4], employing helical baffle as an alternative of segmental baffle, enhanced the performance of the conventional shell and segmental baffle STHE by minimising the pressure drop and fouling. In another experiment, Nemati Taher et al. [5] examined numerically the impact of baffle spacing for the helical baffle STHE. They employed baffles with angle of 20-degree. In the new technique by You et al. [6], they evaluated the computationally based on the porosity and permeability idea in the range of Reynolds numbers from 6,813 to 22,326. Wang et al. [7] proposed floral baffled STHE in an experimental research and compared its performance with ordinary segmental baffle. Wang et al. [7] examined thermo-hydraulic properties of STHE with different type of helical baffle to decrease triangular zones. Helical baffle was introduced to remove the problems of segmental baffle. This was first provided by Lutcha and Nemcansky [8]. Ozden and Tari [9] did a study on tiny STHE in order to evaluate the influence of baffle spacing, baffle cut and shell diameter relationships of the heat transfer coefficient and the pressure drop. They observed good agreement between acquired results and the Bell–- Delaware technique results. Lei et al. [10] examined numerically and experimentally three STHE with different baffle types such as current segmental baffle, single helical baffle and two-layer helical baffle. Based on the obtained data, for the same pressure drop, the two-layer helical baffle exhibit superior performance than others. Zhang et al. [11] explored the angle of helix baffle on STHE with the experimental test whereas Nemati et al. [5] performed it mathematically. Many publications were devoted to the structure of the helical baffles for example: continuous helical baffles [12], coupled helical baffles [13], and combined multiple shell-pass helical baffles [14]. Gorman et al. [15] employed a corrugated construction in an inner tube of twin tube heat exchanger. Ahmed et al. [16] in the numerical research showed the behavior of finned tube with variable configuration in a STHE. Based on their findings, wavy fin configuration exhibited superior performance than others [16]. El Maakoul et al. [17] employed helical baffle to optimize the double pipe heat exchanger. Amini et al. [18] studied the influence of helical and segmental tube sheet on the performance of STHE. There are a lot of investigations that focus on baffles and tubes simultaneously. Liu et al. [19] reported a computational simulation of the shell side flow in rodbaffle heat exchangers with spirally corrugated tubes. Results are compared with those in rod-baffle heat exchanger with plain tubes. Obtained results demonstrated that the thermo–hydraulic performance in spirally corrugated tubes is substantially higher that the rod-baffle heat exchanger with plain tubes. Chen et al. [20] studied the influence of surface roughness on the performance of a typical heat exchanger, and found that the system's performance is somewhat improved. In the work of Ibrahim et al. [21], the thermal-fluid behaviour of the elliptical tube was evaluated in a crossover flow for the aspect ratio of 0.25, 0.33, 0.5. Swain et al. [22] evaluated the heat transfer coefficient and pressure drop over the flat and elliptical tubes. In the investigation, the elliptical tube bundles show superior performance than the flat tubes from the heat transfer viewpoint. In a similar investigation. He et al. [23] did a research on flow characteristic in the shell side of a vertical STHE with coupled helical baffles with elliptic tubes. Obtained results showed that the heat transfer rate, Nusselt number, friction factor and thermal performance factor of the elliptic tubes are 14.7–%-16.4%, 11.4–16.6%, 29.2–36.9% and 30–35%, greater than those of the circular tubes accordingly. Heat exchanger, and the shell side friction factor is decreased by 29.2–36.9%. Referred work reveals that the elliptic tube may effectively improve the heat transfer performance of non-Newtonian fluid flowing in the helical baffle heat exchanger when compared to the circular tube. Shrikant et al. [24] presented a study on the impacts of different baffles configurations, including single, double, triple segmental, helical and floral baffle, inside STHE. Based on acquired results, baffles improved the heat transfer and pressure drop. For the same mass flow rate of shell side, heat transfer rate, heat transfer coefficient and pressure drop are determined to be the best for single segmental baffles. In addition, zero stagnation zones are identified in helical baffles, leading to reduction in fouling. Baffles have a vital purpose, as tubes support, providing shell-side desirable velocity distribution, and preventing from the tubes vibrating. In addition to assembling effects, it can give an essential influence on fluid flow and heat transfer in shell side of STHE, as providing the better local mixing and boosting the turbulence intensity [25], due to establishing the zigzag pattern among the tube bundle. However, there are certain unfavourable impacts on fluid flow and heat transfer as generating the fouling back of baffle plates in the stagnation zone and along the shell wall, producing a considerable pressure drop and creating separation flow near the baffle edge. Due to recent effect more pumping power is needed for the same heat load. Another problem of baffles connected to the providing bypass streams and leakage streams and tube vibrations [2,26]. Therefore, it is vital to present an inquiry on the baffles to magnify the favourable effect and reduce the bad effect. Son and Shin [27] showed that the performance of STHE with helical baffles is superior to that of a conventional STHE due to greater fluid interactions with the tubes and minimising the shell side stagnation zones. In addition to offered inquiry, one can found an investigation that deal with entropy production minimization concepts in heat exchangers in order to boost the heat exchanger performance [28]. Work done by Ashraf Mimi Elsaid et.al. on shell and tube heat exchanger with helical coil with varied inclination angles and usage of nanofluid as a heat transfer medium [29].

1.1 Conclusion for the Literature Survey

In a prior experimental investigation (reference [29]), researchers focused on improving the heat flux of a helical coil heat exchanger by replacing the normal water with a nanofluid. The findings of the experiment revealed an increase in heat transfer rate and increased performance of the heat exchanger. When doing a computational fluid dynamics (CFD) analysis on a helical coil heat exchanger, the meshing of the model becomes intricate, consequently complicating the computation of findings. The helical coil design produces turbulence in the fluid, hence boosting the heat transfer rate. However, to simplify the design and computation process, the helical coil heat exchanger was substituted with a shell and tube heat exchanger containing a flower baffle. The flower baffle serves the same goal as the helical coil in increasing heat transfer. Moreover, this adjustment greatly minimises the complexity of the design. By utilizing the nanofluid, the heat transfer rate is significantly increased. The shell and tube heat exchanger is frequently deployed due to its versatility and adaptability to diverse requirements, making it a great candidate for further development. Consequently, a study was undertaken to analyse the performance of the nanofluid using a basic model of the heat exchanger.

1.2 Heat Exchanger 3-D Model Using ANSYS

Design of shell and tube heat exchanger on ANSYS Workbench 2022, with and without flower baffle. Design the geometry of flower baffles in Solid Works with 44 baffle plates arranged in helical path. Then import this baffle plates to the ANSYS 2022 to complete the geometry of shell and tube heat exchanger. Dimension of the heat exchanger is shown in table 1 and model is shown in the Fig. 1.

Table 1: Dimensions of Heat Exchanger

S. No	Parameter	Value
1	Length of test section	1000 mm
2	Shell diameter	80 mm
3	Tube outer diameter	43 mm
4	Tube inner diameter	40 mm
5	Inlet and outlet diameter of cold and hot fluid	40 mm
6	Thickness of baffle plates	4.5 mm
7	Number of baffle plates	44

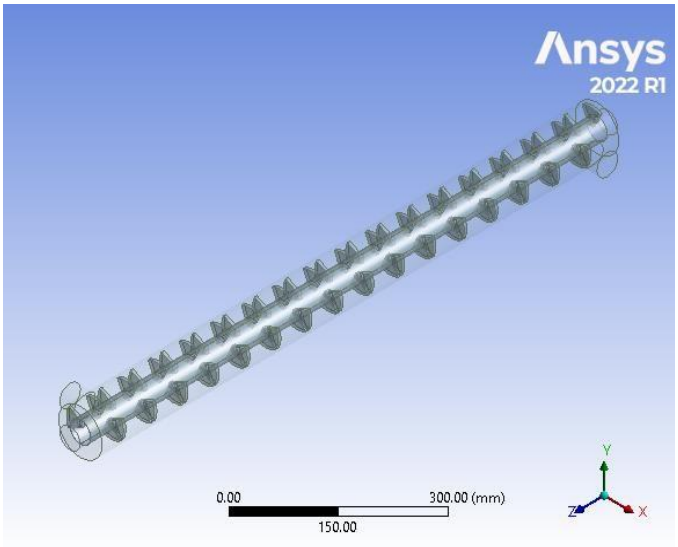

Fig. 1: Model of the heat exchanger.

1.3 Meshing

The computational fluid dynamics (CFD) analysis of shell and tube heat exchangers with a new flower baffle design involves careful consideration of mesh generation and inflation techniques to accurately capture the intricate geometry and complex flow patterns. Meshing plays a vital role in defining the reliability and efficiency of CFD simulations, since it directly effects the solution quality and computational cost. In this study, we address the issues associated in meshing the flower baffle geometry with the surrounding fluid domain. A hybrid approach integrating structured and unstructured meshing approaches is utilised to appropriately resolve the complicated details of the floral baffle. The mesh resolution is chosen to create a compromise between accuracy and computational feasibility. Furthermore, suitable inflation is done to accurately depict the boundary layer near the solid surfaces. The production of thin prism layers of mesh cells ensures accurate resolution of the velocity and heat gradients, important for recording the flow behaviour close to the surface. The meshing and inflation approaches are tested against experimental data and numerical convergence tests. The final mesh quality is tested to guarantee its applicability for credible CFD predictions. By applying these meshing and inflation methodologies, the CFD simulations provide an in-depth insight of the heat transfer properties and convective heat transfer coefficients within the shell and tube heat exchanger with a floral baffle. The findings offer useful insights into the heat exchanger's efficiency and the possible enhancement brought about by the flower baffle design, opening the path for improved heat exchanger designs in numerous industrial applications.

For outcome to be correct, skewness should be limited to 0.88 and aspect ratio should not exceed 650.

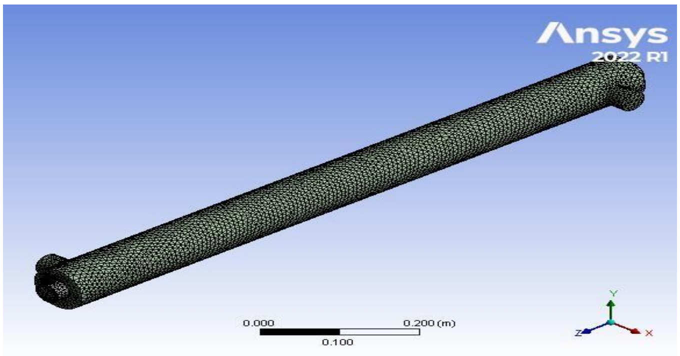

Fig. 2: Meshed geometry

In the context of the counter flow arrangement in the heat exchanger, the naming convention for the inlet and outlet is essential for clear communication and consistency. In this paper, the inlet refers to the point where the hot fluid enters the heat exchanger, and the outlet denotes the location where the hot fluid exits the heat exchanger. Conversely, for the cold fluid, the inlet designates the entry point into the heat exchanger, while the outlet indicates the exit point for the cold fluid. Adhering to this standardized naming convention enables a comprehensive and unambiguous description of the fluid flow and heat transfer phenomena within the counter flow heat exchanger.

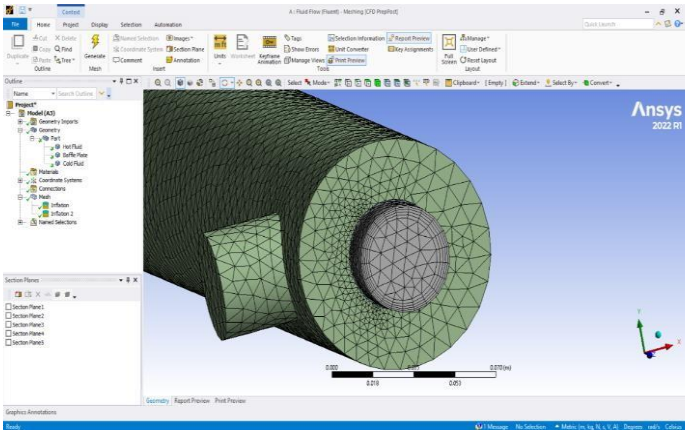

Fig. 3: Inflation

Thermal properties used used for the nanofluid

At volume fraction of 0.6
Nano fluid density (ρ_{nf}):
ρ_{nf} = 2727.28 kg/m^3
Nano fluid specific heat (Cp_{nf}):
Cp_{nf} = 1389.02 J/kg-K
Nano fluid viscosity (μ_{nf}):
μ_{nf} = 0.0025075 kg/m-s
Nano fluid thermal conductivity (K_{nf}):
K_{nf} = 5.13 W/m-K

2. GENERATED CFD REPORT

Below is the report generated by the ANSYS. ANSYS generates the report after every module. The attached report is the material properties used in the analysis and the boundary conditions.

Table 2: Material Properties

Fluid	
water-liquid	
Density	998.2 kg/m^3
Cp (Specific Heat)	4182 J/(kg K)
Thermal Conductivity	0.6 W/(m K)
Viscosity	0.001003 kg/(m s)
Molecular Weight	18.0152 kg/kmol
Thermal Expansion Coefficient	0
Speed of Sound	none
silicon-dioxide	
Density	1492.9 kg/m^3
Cp (Specific Heat)	2346.7 J/(kg K)
Thermal Conductivity	5.79 W/(m K)
Viscosity	0.00175 kg/(m s)
Molecular Weight	28.966 kg/kmol
Thermal Expansion Coefficient	0
Speed of Sound	none
Solid	
aluminum	
Density	2719 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)

3. RESULT AND DISCUSSION

3.1 Heat Flux Shell and Tube Side

In the below mentioned fig. 4, the heat flux value is higher for without flower baffle in comparison with the other case, due to the higher thermal conductivity of nanoparticles present in the nanofluids. They acquire more heat from the hot fluid and increase the wall temperature as well as the heat flux due to the temperature difference. For the heat flux value in the case of without flower baffle has higher heat flux in comparison with the other case but for similar mass flow rate on both side (shell and tube side) with flower baffle has slightly high heat flux value. In the case of baffle plates with similar mass flow rate the heat flux is more for hot fluid. As the difference in mass flow rate increases, there is an increase in heat flux.

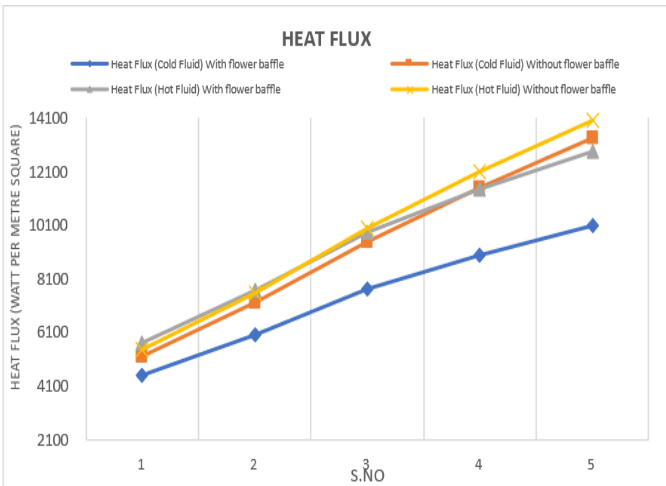

Fig. 4: Graph of heat flux in shell and tube heat exchanger.

3.2 Convective heat transfer coefficient in cold fluid.

As shown in the below fig. 5, the convective heat transfer coefficient for cold fluid is higher for STHX with flower baffle and nanofluid in comparison with STHX with nanofluid only. The flower baffle creates turbulence in cold fluid causing to increase the convective heat transfer coefficient of nanofluid.

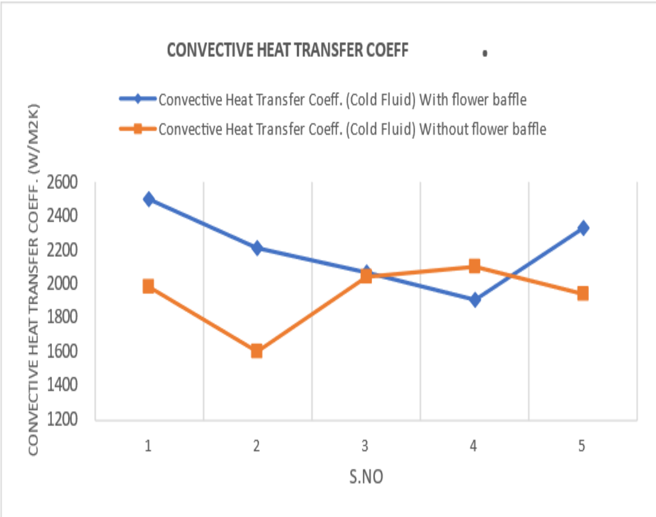

Fig. 5: Graph of Convective heat transfer coefficient in cold fluid.

3.3 Convective heat transfer coefficient in hot fluid.

Whereas, for hot fluid the convective heat transfer coefficient of hot fluid(water) for STHX with nanofluid is high in comparison with other case as shown in fig. 6.

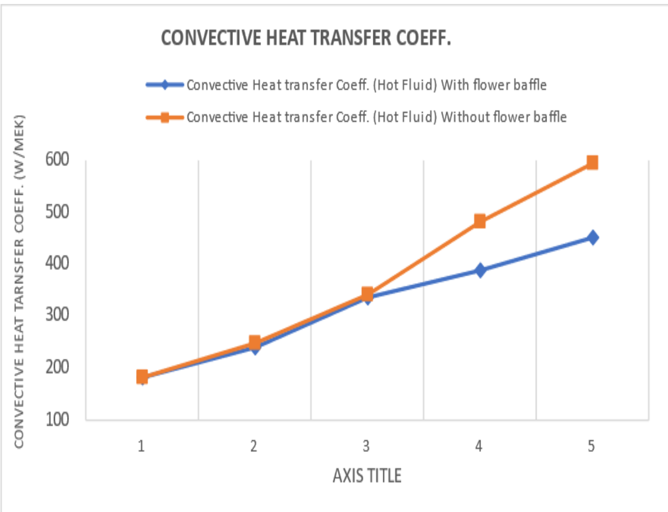

Fig. 6: Graph of Convective heat transfer coefficient in hot fluid

4. CONCLUSION

The nanofluid gives higher heat flux with the increase in the difference in mass flow rate of hot and cold fluid, whereas the combine effect of flower baffle and nanofluid gives a higher convective heat transfer coefficient for cold fluid.
It is evident that in the case of flower baffle with nanofluid keeping the flow rate of 2 lpm and 10 lpm on cold and hot side respectively gives satisfying result with a pressure drop of 4.75Pa on the cold side, and with nanofluid 2 lpm and 8 lpm on cold and hot side respectively gives satisfying result with a pressure drop of 2.48Pa in tube side.
The combined effect of flower baffle and nanofluid SiO2 decreases the pressure drop on the cold side with a constant mass flow rate, whereas in the case of the hot side the pressure drops increase as the mass flow rate increases.
Above results indicates that with low-pressure drop-in tube side SiO2 nanofluid gives higher heat flux.

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